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The research program was divided into main areas:

- **Semiconductor Materials, Processes and Circuits**
- **Information Systems**

The work units and tasks within each of the above areas are summarized below, the investigator responsible for the unit.

1. **Semiconductor Materials, Processes and Circuits**
   a. **Molecular Beam Epitaxy of High T_C Superconductors**
   b. **Physics and Applications of Ultra-Small, High Temperature Superconductors**

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e. The Electronic Structure and Interfacial Properties of High Temperature Superconductors (W. E. Spicer)
f. Semiconductor Laser Structures for Optical Interconnects
g. Quantum Computing
h. Applications of SiGe in MOS Technologies

2. Information Systems
   a. Packet Equalization
   b. Fast Arithmetic Computing with Neural Networks

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SOLID STATE
ELECTRONICS
LABORATORY

JSEP FINAL REPORT

July 1, 1988 through January 10, 1991

J. S. Harris
Principal Investigator
Program Director
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STANFORD ELECTRONICS LABORATORIES • DEPARTMENT OF ELECTRICAL ENGINEERING
STANFORD UNIVERSITY • STANFORD, CA 94305-4055

JSEP Final Report

Period of July 1, 1988 - January 10, 1991

Department of Electrical Engineering
Stanford University
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Joint Services Electronics Program
(U.S. Army, U.S. Navy and U.S. Air Force)
Contract DAAL03-88-C-0011

J. S. Harris
Principal Investigator
Program Director

Monitored by U.S. Army Research Office

Abstract

This is the final report of the research conducted at Stanford Electronics Laboratories under the sponsorship of the Joint Services Electronics Program from July 1, 1988 through January 10, 1991. This report summarizes the areas of research, identifies the most significant results and lists the dissertations, publications and presentations sponsored by the contract (DAAL03-88-C-0011).

Key Words and Phrases: None

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1. INTRODUCTION

This report summarizes the activities in the research programs at the Stanford Electronics Laboratories sponsored by the Joint Services Electronics Program under contract DAAL03-88-C-0011. This contract is monitored by the Army Research Office, Research Triangle Park, North Carolina.

This report covers a period of significant change in the Stanford JSEP program. Three of the six initial projects were new, and during the course of the three year program, two new projects were initiated in the second year and one of the initial projects was completely changed in the third year. Thus, the program at the end of the three year period had fewer than half of the initial projects. This was not a reflection of needed change from the quality of the projects, but a conscious decision to focus JSEP funds on seeding new ideas and projects which could lead to larger programs with conventional DoD funding, but would take one to two years to proceed through the proposal process. The JSEP flexibility provides great leverage in seeding such new ideas in the interim period when virtually nothing would otherwise occur.

The research program is divided into main areas:

- Semiconductor Materials, Processes and Circuits
- Information Systems

The work units and tasks within each of the above areas are summarized below, together with the investigator responsible for the unit.

1. Semiconductor Materials, Processes and Circuits
   a. Molecular Beam Epitaxy of High T_C Superconductors (J. S. Harris)
   b. Physics and Applications of Ultra-Small, High Temperature Superconductors (R. F. W. Pease)
   c. Reactive Ion Profiling of Heterostructures (C. R. Helms)
   d. GaAs on Si Integrated Circuits (B. A. Wooley)
   e. The Electronic Structure and Interfacial Properties of High Temperature Superconductors (W. E. Spicer)
   f. Semiconductor Laser Structures for Optical Interconnects (S. S. Wong)
   g. Quantum Computing (J. D. Plummer)
   h. Applications of SiGe in MOS Technologies (K. C. Saraswat)

2. Information Systems
   a. Packet Equalization (J. M. Cioffi)
   b. Fast Arithmetic Computing with Neural Networks (T. Kailath)

2. SIGNIFICANT RESULTS

The most significant accomplishments, as determined by the JSEP Principal Investigator and Director, are summarized as follows:

- *Molecular Beam Epitaxy of High Tc Superconductors*

The Molecular Beam Epitaxial (MBE) growth of high temperature superconductors is a strong collaboration with researchers at Varian Associates and has resulted in a substantial DARPA contract. The ability of MBE to grow in-situ layered, metastable-like compounds has been demonstrated. This is a major step in the development of artificially layered combinations of perovskite-related compounds. Low temperature growth is required to grow metastable layered $Bi_2Sr_2Ca_{n-1}Cu_nO_x$ structures, particularly for any attempt to combine these compounds with other electronic materials. We have demonstrated the first true single crystal growth of $Bi_2Sr_2Ca_{n-1}Cu_nO_x$ by any technique. This was achieved by in-situ MBE growth on a vicinal or misoriented $SrTiO_3$ substrate.

- *Application of SiGe in MOS Technologies*

Low temperature processing is becoming increasingly important. Si films become amorphous when deposited below 600°C, thus limiting the quality of low temperature films for thin film transistors (TFT) and poly gates for MOSFETs. Poly SiGe films have been deposited by LPCVD at 500°C with 0.2 the sheet resistance for poly Si films and 0.5 the sheet resistance for poly Si films deposited at 900°C. The SiGe films may produce vastly improved TFTs on glass for large area displays as well as lower resistivity poly gates and adjustment of the gate workfunction in conventional VLSI technology.

- *Fast Arithmetic Computing with Neural Networks*

One of the basic assumptions in neural networks is that we allow the neural elements to take on an unbounded number of inputs, i.e., we allow unbounded fan-in. By exploiting this feature, we have to shown the following interesting results: the sum and product of two n-bit numbers, and sorting of n n-bit numbers can all be done with 4 unit delays with neural networks. We have extended our results to more complicated functions and have shown that exponentiation and division can be computed with 5 unit delays, and multiple product can be computed with 6 unit delays, with neural networks.

3. SEMICONDUCTOR MATERIALS, PROCESSES AND CIRCUITS

3.1 Molecular Beam Epitaxy of High T_c Superconductors and Investigation of *Quantum Well Structures*

The polycrystalline nature of the ceramic forms of the high T_c materials is likely to be unsuitable for electronics applications. In addition, the very short coherence lengths of these superconductors has made it difficult to prepare thin film tunnel junctions in the usual ways. The ideal form of these materials is thus likely to be that of epitaxial films, prepared in such a way that composition and structure can be controlled at the atomic layer level. Because of the controlled layering possible with molecular beam epitaxy (MBE), we have focused on syntactic intergrowth of $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4}$ phases where n ranges from 1 to 5. We have chosen this family of superconductors because the free energy of formation appears virtually degenerate for all phases of these materials, thus bulk and even controlled thin film growth results in small polycrystalline regions of different phases. Controlled layering offers an unparalleled opportunity to fabricate metastable superlattice mixtures to test high T_c theories, and may allow the growth of higher temperature superconducting compounds, once a proper theory is established. It is with these goals in mind that we have undertaken a systematic study of the growth of $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4}$ by MBE in collaboration with the MBE group at the Varian Research Center.

Previously, epitaxial layers produced by MBE and other deposition techniques have been oriented epitaxial layers. Although the crystallographic directions in the film are strongly influenced by the crystallographic form of the substrate (epitaxy), the presence of reflection twin boundaries or 90° rotation twin boundaries in both the $DyBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2Ca_{n-1}Cu_nO_x$ grown films distinguish these films from true single crystals. These reflection twin boundaries are not unlike the antiphase domains that occurred in early attempts to grow GaAs on Si. The solution to this problem was growth on intentionally misoriented substrates. Our superconductor work was initially done on carefully oriented substrates, however, we had some accidentally misoriented $SrTiO_3$. Growth on one of these accidentally misoriented $SrTiO_3$ (001) substrates, (misoriented about 3.8° → [110] and 0.9° → [110] as measured by the Laue method), produced the growth of the first true single crystal 2223 film by any technique.

Resonant tunneling models have ignored the effects of accumulation layers, spacers, etc., in the cathode region. We have focused our efforts on understanding the role of the cathode region and its role in optimizing device design. The first efforts to improve RTD performance were believed to be imputity effects and reduced scattering, which improved the PVCR to 3.5 (10.0) at 300K (77K) in AlAs/GaAs DBRTDs. Subsequently, a two step spacer structure DBRTD increased the PVCRs to 3.6 (21.7) at 300K (77K) in an AlAs/GaAs superlattice barrier DBRTDs and to 3.9 (14.3) at 300K (77K) in an alloy barrier DBRTD with x=0.42 (where x is Al

composition). This project was the first to really focus on the role of the cathode region. Initially, we investigated the role of X valley tunneling, which led to investigation of the role of wider, low energy "chair" barriers on both X valley tunneling and tunneling form the accumulation layer in the cathode. Record values of PVCR of 6.0 were observed for DBRTDs in the GaAs/AlGaAs system. These improvements in RTD design should enhance the performance of millimeter wave DBRTDs as well as devices into which DBRTDs have also been incorporated, such as bipolar transistors and three terminal quantum wire structures.

3.2 Physics and Applications of Ultra-Small, High-Temperature Superconductors

The overall objective of this program is to investigate opportunities for new devices whose operation depends on quantum mechanical effects associated with the ultrasmall (< 100nm) dimensions of these devices. During the relevant reporting period we had two specific goals: to conclude the first project on lateral quantum well devices employing compound 3-5 semiconductors and to initiate the project on ultrasmall superconducting structures.

Significant Results

The project on lateral quantum well devices has been successfully concluded. In particular we demonstrated resonant tunneling phenomena in a variety of multi-gate MODFET structures with gate electrode geometries down to 50nm. We observed, as either gate voltage or drain voltage was varied conductance maxima and minima and showed that these became more pronounced as we proceeded from 2-dimensional to 3-dimensional confinement of the carriers.

The project on ultrasmall superconducting structures and devices was initiated in late 1989 with a view to fabricating weak link structures in YBCO films using ultrahigh resolution electron beam lithography. After the preliminary phase (reported in the 1990 annual report) this project became part of a contract supported by AFOSR.

A new research opportunity for an ultrasmall derive emerged in 1990. This is the bandgap-engineered, monochromatic electron emitter (see proposal for the current year). The principle is to combine the semiconductor junction emitter with a resonant tunneling structure for monochromaticity. The first structures have been built and are now being evaluated.

3.3 Reactive Ion Profiling of Heterostructures

The objective of this work was to determine the surface chemistry associated with the interaction of reactive ions with GaAs and other III-V surfaces. We are also continuing work begun on the previous program on metal-GaAs interfaces [Kniffin, 1990]

In addition, since the program began, new results have also appeared indicating the utility of low temperature deposition and etching in downstream plasma reactors (in both RF and ECR

microwave configurations). With this in mind we constructed a UHV compatible downstream plasma source which will initially be used to investigate cleaning and etching of III-V surfaces and Device Structures.

Key results of these studies will now be summarized. In the area of GaAs contacts, two major contributions will be discussed. In the first [Kniffin, 1990], [Kniffin, Helms, 1990] Ga alloy contacts to Ag were fabricated showing remarkable metallurgical, thermal stability and anomalously low n-type barrier heights. In the second, a process using H2/H2O oxidation equilibria was developed to produce single phase PtAs contacts with a Ga2O3 outer skin that could be etched off [Weiss, 1990] [Weiss, 1991]. In the second area, the remote plasma reactor has been completed including an additional atomic hydrogen source. Initial studies of diamond surfaces with AES and EELS as a function of temperature and ion damage have been performed. Additional studies of GaAs surface passivation are underway.

3.4 GaAs on Si Integrated Circuits

The principal focus of this research has been on the design and integration of fiber-optic receiver front ends in GaAs/Si technology. In fiber-optic communication systems, stringent bandwidth and sensitivity requirements are placed on the receiver electronics. These requirements are especially significant at the front end of the receiver, where optical information is converted to an electronic format and subsequently amplified by a preamplifier. Monolithic integration of the photodetector and the preamplifier offer significant improvement in performance by reducing the parasitics associated with the interconnection between these components.

Our approach to investigate GaAs/Si optical receivers has been to fabricate a GaAs photodetecting diode on a silicon substrate in which a receiver front end has been integrated in Si bipolar or CMOS technologies. We demonstrated a functional, fully integrated GaAs/Si receiver front end, which consisted of a GaAs metal-semiconductor-metal (MSM) photodetector and a Si bipolar preamplifier. This was the first reported integration of GaAs components and Si bipolar circuits. We also describe efforts toward improving the process flow for the integration of GaAs and Si devices, with the objective of simplifying the integration of the back-end processing steps that follow the fabrication of the Si devices and GaAs epitaxial growth.

3.5 The Electronic Structure of High Temperature Superconductors

We have focused on the applications of photoemission spectroscopy (primarily in the angle-resolved mode) to the study of the high temperature superconductors and related materials. We have studied fundamental physics problems such as the nature and origin of the near Fermi level electronic states and the superconducting excitations, and, due to the surface sensitivity of the

technique, we have been able to study the technologically important interfaces of the high T_c superconductors with other materials. Very high quality single crystalline and thin film samples have been obtained primarily by a collaboration with the Kapitulnik-Geballe-Beasley group at Stanford.

Our interface studies showed that of all materials gold forms the cleanest and most abrupt interfaces with the high Tcs. However, the gold/high Tc interface was not found to be perfect, for the metallicity of the near surface region of $YBa_2Cu_3O_{7-d}$ is affected by gold deposition. The $Bi_2Sr_2CaCu_2O_{8+d}$ surface was found to be more robust, with little or no degradation in the metallicity of the near surface region. These interface studies came to a culmination in our search for a proximity effect induced superconducting gap in gold overlayers on the high T_cs. Due to the above mentioned studies the gold/$Bi_2Sr_2CaCu_2O_{8+d}$ system was chosen. In addition, we studied gold/thin-film $YBa_2Cu_3O_{7-d}$ junctions which were oriented so that the superconducting planes were perpendicular to the surface. These junctions had the benefit that the superconducting coherence length across the interface was much greater, though the interface quality was not as great. We directly searched for the effects of a superconducting gap in the surface layer (gold) with high-resolution, temperature-dependent photoemission spectroscopy. We did not observe such an effect, but were able to place an upper limit of approximately 5 meV on its existence, which is well below the superconducting gap value of approximately 20-25 meV in the bulk high T_c superconductor.

In addition to information about the proximity effect, the above experiments provided some additional insight into the nature of the surface-like versus the bulk-like states of $Bi_2Sr_2CaCu_2O_{8+d}$. Our results showed that submonolayer coverages of gold on the surface of $Bi_2Sr_2CaCu_2O_{8+d}$ destroyed the near Fermi level states in some portions of the Brillioun zone (along the zone diagonal), while the states in other regions of the Brillioun zone (along G-X) were essentially unaffected. Combined with our previous experimental results that the surface layer of a cleaved crystal is a Bi-O plane, we interpreted this to mean that the states along that were destroyed by the gold deposition had more surface-like or Bi-O character, while the states along G-X had little or no Bi-O character and so were largely Cu-O derived. These results were consistent with the results of band structure calculations. A further very interesting result from this study is that the states along which are more surface related show a very clear and strong superconducting energy gap. This is unexpected based on continuum Ginzburg-Landau theory.

By taking advantage of the polarized nature of the synchrotron radiation we were in another study able to infer that the states near the Fermi level of $Bi_2Sr_2CaCu_2O_{8+d}$ were primarily of D5 symmetry (O 2px and O 2py) while the states at the highest valence band binding energies were of D1 symmetry (O 2pz). A further set of studies used resonance photoemission spectroscopy to study the effects of Pr doping in $Y_{1-x}PrxBa_2Cu_3O_7$ and $Pb_2Sr_2PrCu_3O_8$. The main thrust of

these studies was to determine the cause of the quenching of the superconductivity in $Y_{1-x}Pr_xBa_2Cu_3O_7$ as the Pr concentration is increased (Pr is alone among the rare earths in its ability to quench the superconductivity). Our data suggests that the amount of hybridization between the Pr and the Cu-O valence states is a critical factor for the quenching of the superconductivity.

3.6 Semiconductor Laser with Ultra-Low Threshold Current

The objective of this work is to study the interplay between geometry and physics in a semiconductor laser in order to achieve ultra-low threshold current and high efficiency for applications in inter-chip optical data communication. Optical links can potentially deliver the high data rate required for future integrated systems. Because of the large number of semiconductor lasers involved, the threshold current and the quantum efficiency of the lasers will play a key role in determining the power dissipation, reliability and overall efficiency of the system.

This project was initiated in July of 1989. During the last one and a half years, we have concentrated on developing the technology for patterning and etching quantum wire structures, which are expected to reduce the threshold current and improve the efficiency of semiconductor lasers. In order to observe quantum wire effect, lateral dimension has to be on the order of 100 nm. We are fine tuning the electron beam direct write lithography to pattern such fine lines. Although the spacings will most likely be larger, we should be able to observe the quantum effect. A method to create the quantum wire structure is to use a highly anisotropic dry etching technique we have developed for etching laser facets. The technique has been applied to etch vertical and smooth facets for GaAs/AlGaAs lasers; to fabricate lasers with V-shaped and triangular cavities; to form monolithic ridge lasers; and to demonstrate uni-directional travelling wave operation in a triangular ridge laser with a ridge width chosen to allow only one lateral mode.

3.7 Device Physics and Technology of Silicon Based Heterostructures

The central objective of this research project was to develop a numerical simulation capability for quantum effect electronic (as opposed tooptoelectronic) devices. Such a simulation tool is needed to accelerate anddirect research of quantum effect dominated devices such as resonanttunneling diodes (RTD's) and transistors (RTTs), which may represent thefuture of ULSI electronics.

During the course of this project, the basic objective of developing aquantum electronic device simulation capability was achieved. Our numerical simulator is based on solving the quantum transport equation for the Wigner function (analogous to the Boltzmann transport equation in classical mechanics). The simulator can model the operation of a general 1-D quantum structure in either the SiGe or GaAs material system. In steady-state mode, the simulator produces either detailed information about device operation at a single bias point, or an I-V curve. In this mode,

simulated SiGe RTDs showed the characteristic negative differential resistance region in the I-V characteristic, with a peak-to-valley current ratio of over 2 at room temperature. The simulator also has a transient simulation mode. In this mode, a SiGe RTD switched from resonance to anti-resonance reached a steady-state current in about 80 fs. Two important effects, self-consistency and scattering, are in the process of being implemented in our Wigner function simulator.

We have also implemented a steady-state quantum device simulator using the most prevalent (due to its simplicity) method of quantum device simulation, which is based on the calculation of transmission matricies. There are advantages and disadvantages of the Wigner function and T-matrix approaches, and our implementation of both gives us access to the benefits of each.

We are just beginning an experimental phase of this work, to proceed in parallel with the simulation work. The goal of this experimental work is to apply and test the quantum device simulator's predictions. SiGe RTDs (and related structures) will be fabricated in collaboration with UCLA to allow a comparison of measured results and simulator predictions. Comparisons to date between simulated results for RTDs and measurments published by other researchers have shown reasonable agreement for both SiGe and GaAs devices in both steady-state and transient modes.

Several internal review-type reports also resulted from this work. The basic purpose of these was to make a critical analysis of the field of quantum computing (i.e., electronics based on quantum effect devices), and thereby to provide clear directions for future simulation and experimental research for this project. These reports cover such topics as the general nature of quantum computing and quantum computing devices, a review of the various approaches to simulating quantum systems, and an analysis of the optimization of the RTD.

3.8 MOS Devices Based on the Ge_xSi_{1-x}/Si Materials System

In this project we have been investigating feasibility to fabricate MOS transistors in single crystal and polycrystalline films of germanium/silicon. Because enhancements in both hole and electron mobilities have been observed in strained epitaxial alloys of SiGe (compared to silicon), we initially investigated the formation of thin epitaxial layers of SiGe on silicon, with the intent to eventually fabricate surface-channel MOSFETs on these heterostructure substrates. The thin epitaxial layers were formed by steam oxidation of Ge-implanted silicon, a method which was attractive because of the widespread availability and relatively low cost of ion implantation (compared to chemical vapor deposition and molecular-beam epitaxy). Although we were able to obtain strained SiGe layers by this method, the properties of the resultant $SiGe/SiO_2$ interface were poor (characterized by a very high interface trap density) and therefore not suitable for MOS applications.

We next investigated the application of polycrystalline SiGe films to MOS technology. The first application investigated was as the gate material in a MOS technology. It was found that P+ poly-SiGe is a very good candidate for the gate material in a CMOS technology due to its lower resistivity (compared to poly-Si) and its workfunction (which can be modified to achieve more-scalable NMOS and PMOS devices). It was also found that significantly lower anneal temperatures (as low as 500 degrees C) were sufficient to achieve a high degree of dopant activation in poly-SiGe, compared to poly-Si, so that poly-SiGe may be an attractive alternative to poly-Si in technologies which have limited thermal budget requirements.

This realization has led to a new invention on fabrication of thin film transistors (TFTs) at low temperatures. We have successfully fabricated p-channel MOS transistors in thin poly-SiGe films using either a low-temperature (less than 600 degrees C) process or a high-temperature (up to 950° C) process. The transistors exhibited excellent I-V device characteristics, indicating that poly-SiGe TFTs may provide an advantage over poly-Si TFTs in applications such as stacked CMOS technologies (e.g., SRAMs the TFTs are used as the PMOS load devices) and, more notably, large-area display driver technologies. We believe that display drivers and SRAMs with GeSi MOS TFTs will offer low temperature processing (< 500 degrees C) and significantly better performance than presently available through the use of polycrystalline or amorphous silicon TFTs. This technology will allow the fabrication of high performance MOS TFTs on low cost substrates, such as, glass, without adding any additional fabrication process complexity.

4. INFORMATION SYSTEMS

4.1 Combined Equalization and Coding

The scientific objective has been the study of signal processing and coding methods that enhance the performance of digital mobile communication links. We call this study "packet equalization." Focus has been on reliable transmission in the presence of time-varying multipath and adjacent-channel distortion.

We have developed a theory that accurately predicts the physical performance of data transmission on time-varying mobile communication channels. This theory allows one to make wise choices of the critical system parameters in designing the data links for a mobile digital communications link. The theory relates the probability-of-error to the rate of channel variation (Doppler shift) and to the severity of multipath fading for any choice of sampling rate, data-packet length, and training overhead. The new theory predicts unusual effects that had been observed but not previously understood. We have used the theory to evaluate some of the systems choices that have been recently made (on an empirical basis alone) in some upcoming digital cellular networks in the commercial sector, the IS-54 North American time-division multiple access standard and the Group Special Mobile European time-division multiple access standard. These

results are described in more detail in [1], a recently submitted publication by graduate student Rob Ziegler and the investigator. Further results on the desirability of training on unknown data within a packet are forthcoming in Ziegler's upcoming dissertation (he will matriculate by 9/91).

We have also developed a method for fast computation of mobile receiver parameters (on a per-packet basis) that requires an order of magnitude less instructions (less MIPS) on a programmable digital signal processor to implement. We have constructed a state-of-the-art multi-processor scheme for mobile communications in real time. We have also developed a method that we call the "spread-spectrum decision feedback equalizer" that allows a larger number of users when multipath fading occurs in code-division multiple-access data communication. We also list below two other partially JSEP-supported papers ([2], [3]) on previously supported work in the are of high-speed digital subscriber line data transmission.

4.2 Real-Time Statistical Signal Processing

The goals of this research program have been twofold: a) to study the computational power of neural networks for arithmetic computations, b) to study the direction-of-arrival (DOA) estimation and adaptive beamforming problems, particularly in the presence of "coherent" interference which arises in "multipath" and "smart" jammer environments.

5. JSEP SUPPORTED DISSERTATIONS

1. D. G. Schlom, "Molecular Beam Epitaxial Growth of Cuprate Superconductors and Related Phases", Ph.D. Dissertation, Stanford University, Stanford, CA, June, 1990.
2. P. Cheng, "Novel Tunneling Barrier Designs for Resonant Tunneling Diodes", Ph.D. Dissertation, Stanford University, Stanford, CA, January, 1991.
3. D. R. Allee "Nanometer Scale Device Engineering", Ph.D. Dissertation, Stanford Electronics Laboratory, Stanford, CA, August 1989.
4. A. Ruiz, "Frequency-Designed Coded Modulation For Channels with Intersymbol Interference", Dissertation, Department of Electrical Engineering, January 1989.
5. P. Fortier, "Multidimensional Signal Set Design for Transmission Over Parallel Channels", Dissertation, Department of Electrical Engineering, May 1989.
6. S. Kasturia, "Vector Coding for Digital Communications on Spectrally Shaped Channels", Dissertation, Department of Electrical Engineering, December 1988.
7. M. L. Kniffen, "The Effects of Interfacial Chemistry on the Properties of Schottky Contacts to GaAs", Department of Electrical Engineering, November 1990.

6. JSEP SUPPORTED PUBLICATIONS

1. J. S. Harris, Jr., J. N. Eckstein, E. S. Hellman, and D. G. Schlom, "MBE Growth of High Critical Temperature Superconductors," *J. Crystal Growth* **95**, 607 (1989).
2. P. Cheng and J. S. Harris, Jr., "Effect of Si doping in AlAs barrier layers of AlAs-GaAs-AlAs double-barrier resonant tunneling diodes", *Appl. Phys. Lett.* **55**, 572 (1989).
3. E. S. Hellman, D. G. Schlom, A. F. Marshall, S. K. Streiffer, J. S. Harris, Jr., M. R. Beasley, J. C. Bravman, T. H. Geballe, J. N. Eckstein and C. Webb, "Phase Characterization of Dysprosium Barium Copper Oxide Thin Films Grown on Strontium Titanate by Molecular Beam Epitaxy," *J. Mater. Res.*, **4**, (3), pp. 476-495, May/Jun 1989.
4. J. S. Harris, Jr., J. N. Eckstein, E. S. Hellman and D. G. Schlom, "MBE Growth of High Critical Temperature Superconductors," *J. of Crystal Growth* **95**, pp. 607-616, 1989.
5. P. Cheng, B. G. Park, S. D. Kim and J. S. Harris, Jr., "The X-Valley Transport in GaAs/AlAs Triple Barrier Structures" *J. Appl. Phys.* **65**, (12), June 1989.
6. J. N. Eckstein, J. S. Harris, Jr., D. G. Schlom, I. Bozovic, K. E. von Dessoneck and Z. J. Chen, "Development of Molecular Beam Epitaxial Growth of High Temperature Superconducting Compounds," *International Superconductivity Electronics Conf.*, Tokyo, Japan, June 1989.
7. P. Cheng and J. S. Harris, Jr., "The Effect of Si Doping in AlAs Barrier Layers of AlAs-GaAs-AlAs Double Barrier Resonant Tunneling Diodes," *Appl. Phys. Lett.* **55**, (6), August 1989.
8. S. Y. Chou, D. R. Allee, R. F. W. Pease and J. S. Harris, Jr., "New Lateral Resonant Tunneling FETs Fabricated Using Molecular Beam Epitaxy and Ultra-High Resolution

Electron Beam Lithography", *Proceedings of 16th International Symposium on GaAs and Related Compounds*, Karuizawa, Japan, pp. 875-879, September 1989.

9. D. G. Schlom, J. N. Eckstein, I. Bozovic, A. F. Marshall, J. T. Sizemore, Z. J. Chen, K. E. Von Dessonneck, J. S. Harris, Jr. and J. C. Bravman, "Molecular Beam Epitaxy of Layered Bi-Sr-Ca-Cu-O Compounds," *Proceedings of Fall Materials Research Society Symposium M: High-Temperature Superconductors*, November 1989.

10. D. G. Schlom, A. F. Marshall, J. T. Sizemore, Z. J. Chen, J. N. Eckstein, I. Bozovic, K. E. von Dessonneck and J. S. Harris, Jr., "Molecular Beam Epitaxial Growth of Layered Bi-Sr-Ca-Cu-O Compounds," *Jrnl. Cryst. Gwth.*, **102**, pp. 361-375, February 1990.

11. D. G. Schlom, J. N. Eckstein, I. Bozovic, A. J. Chen, A. F. Marshall, K. E. von Dessonneck, J. S. Harris, Jr., "Molecular Beam Epitaxy-a Path to Novel High T_c Supercondonductors," *Proceedings of Growth of Semiconductor Structures and High-T_c Thin Films on Semiconductors*," SPIE, **1285**, pp. 234-247, March 1990.

12. P. Cheng and J. S. Harris, Jr., " Improved Design of AlAs/GaAs Resonant Tunneling Diodes", *proceedings SPIE Conference - "Quantum Well and Superlattice Physics III"*, **1283**, 353-358, March 1990.

13. J. H. Kim, I. Bozovic, D. B. Mitzi and A. Kapitulnik and J. S. Harris., Jr., "Optical Anisotropy of $Bi_2Sr_2CaCu_20_8$," *Phys. Rev. B*, **41**, 10, April 1990.

14. P. Cheng and J. S. Harris, Jr., "Improved Design of AlAs/GaAs Resonant Tunneling Diodes", *Appl. Phys. Lett.* **56** (17) April 23, 1990.

15. K. Kojima, D. G. Schlom, K. Kuroda, M. Tanioku, K. Hamanaka, J. N. Eckstein and J. S. Harris, Jr., "Superstructure in Thin Films of Bi-Based Compounds on MgO," *Japanese Jrnl of Appl. Phys*, **29**, 9, pp. L1638-L1641, September 1990.

16. J. N. Eckstein, I. Bozovic, D. G. Schlom and J. S. Harris, Jr., "Growth of untwinned $Bi_2Sr_2Ca_2Cu_3O_8$ Thin Films y Atomically Layered Epitaxy," *Appl. Phys. Lett.* **57**, pp 1049-1051, September 1990.

17. D. G. Schlom, A. F. Marshall, J. S. Harris, Jr., I. Bozovic and J. N. Eckstein, "Growth of Metastable Phases and Superlattice Structures of Bi-Sr-Ca-Cu-0 Compounds by an Atomic Layering MBE Technicque", *Proceedings 3rd Int'l. Symp. on Superconductivity*, Sendai, Japan, November 1990.

18. D. R. Allee, S. Y. Chou, J. S. Harris, Jr., and R. F. W. Pease, " Resonant Tunneling of 1-Dimensional Electrons Across an Array of 3-Dimensionally Confined Potential Wells," *Superlattices and Microstructures*, **7**, (2), pg. 131-134, 1990.

19. D. R. Allee, J. D. Pehoushek and R. F. W. Pease, "Novel Monte Carlo simulation of space-charge-induced energy broadening laser irradiated cathodes," *J. Vac. Sci. Technol.*, **B6**, (6), 1989, Nov/Dec 1988.

20. S. Y. Chou, D. R. Allee, R. F. W. Pease and J. S. Harris, Jr., "Observation of electron resonant tunneling in a lateral dual-gate resonant tunneling field-effect transistor," *Appl.*

Phys. Lett., **55**, (2) 176, 1989).
21. D. R. Allee, S. Y. Chou, J. S. Harris, Jr. and R. F. W. Pease, "Engineering Lateral Quantum-Well Devices Using Electron Beam Lithography and Molecular Beam Epitaxy", *J. Vac. Sci. Tech.*, **B7** (6), Nov/Dec 1989.
22. S. Y.Chou, D. R. Allee, R. F. W. Pease and J. S. Harris, Jr., "Observation of Electron Resonant Tunneling in a Lateral Dual-Gate Resonant Tunneling Field-Effect Transistor," *Appl. Phys. Lett.* **55** (2), July 1989.
23. D. R. Allee, S. Y. Chou, J. S. Harris, Jr. and R. F. W. Pease, "Resonant Tunneling of 1-Dimensional Electrons Across an Array of 3-Dimensionally Confined Potential Wells", *Superlattices and Microstructures* **Vol. 7**, No. 2, 1990.
24. K. B. Kim, M. Kniffin, R. Sinclair, C. R. Helms, "Interfacial Reactions in the Ti/GaAs System", *J. Vac. Sci. Tech.* **A6**, 1473 (1988).
25. G. Scott, K. Ninomiya, C. R. Helms, I. Lindau, "Auger Analysis of Si Sputtered with Ar+ Ions in an F^2 Ambient", *Surface Science*, **221** 253-262 (1989).
26. M. Kniffin and C. R. Helms "The Synthesis and Properties of Low Barrier Ag-Ga Intermetallic Contacts to n-type GaAs" *J. Appl. Phys.* **68**, 1367 (1990).
27. E. Weiss, R. C. Keller, M. Kniffin and C. R. Helms, "Selective Oxidation and Etching of Reacted Pt Films on GaAs", *Mat. Res. Soc. Symp. Proc.* **181**, 253 (1990).

28. Z.-X. Shen, P. A. P. Lindberg, B. O. Wells, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Valence Band and Core Level Photoemission Study of Single-Crystal $Bi_2Sr_2CaCu_2O_8$ Superconductors", *Phys. Rev. B* **38**, 11820 (1988).
29. Z.-X. Shen, P. A. P. Lindberg, D. S. Dessau, I. Lindau, D. B. Mitzi, I. Bozovic and A. Kapitulnik, "Photoelectron energy-loss study of the $Bi_2Sr_2CaCu_2O_8$ superconductor", *Phys. Rev. B* **39**, 4295 (1988).
30. Z.-X. Shen, P. A. P. Lindberg, W. E. Spicer, I. Lindau and J. W. Allen (Invited paper), "Photoemission Study of High Temperature Superconductors", {Invited paper for AVS, 1988, Atlanta} to be published in the *AIP/AVS Conference Proceedings,* 182, (1989).
31. Z.-X. Shen, P. A. P. Lindberg, B. O. Wells, I. Lindau, W. E. Spicer, P. Soukiassian, D. B. Mitzi, C. B. Eom, A. Kapitulnik and T. H. Geballe, "Surface and Electronic Structure of Bi-Ca-Sr-Cu-O Superconductors Studied Using LEED, UPS and XPS", to be published in the *AIP/AVS Conference Proceedings,* 182, (1989).
32. P. A. P. Lindberg, Z.-X. Shen, I. Lindau, W. E. Spicer, C. B. Eom and T. H. Geballe, "Photoemission study of the surface electronic structure of Bi-Ca-Sr-Cu-O superconductors modified by Ne-sputtering, Ag-deposition and heat treatment", *Appl. Phys. Lett.* **53**, 529 (1988).
33. P.A.P. Lindberg, P. Soukiassian, Z.-X. Shen, C. B. Eom, I. Lindau, W. E. Spicer, T. H. Geballe, "Electronic structure of ceramics and thin film samples of high-Tc $Bi_2Sr_2CaCu_2O_8$ superconductors: effects of Ar^+-sputtering, O2-exposure and Rb-deposition", *Appl. Phys.*

Lett., **53**, 1970 (1988).

34. P.A. P. Lindberg, Z.-X. Shen, B. O. Wells, D. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Surface strcture of $Bi_2Sr_2CaCu_2O_8$ high-temperature superconductor studied using low-energy electron diffraction", *Appl. Phys. Lett.* **53**, 2563 (1988).
35. B. O. Wells, P. A. P. Lindberg, Z.-X. Shen, D. S. Dessau, I. Lindau, W. E. Spicer, D. B. Mitzi and A. Kapitulnik, "Aluminum and Gold Deposition on Cleaved Single Crystals of $Bi_2Sr_2CaCu_2O_8$ Superconductors", to be published in the *AIP/AVS Conference Proceedings* 182, 1989.
36. P. A. P. Lindberg, Z.-X. Shen, B. O. Wells, D. S. Dessau, D. R. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Reaction of Rb and oxygen overlayers with single-crystalline $Bi_2Sr_2CaCu_2O_8$ superconduc-tors" *Phys. Rev. B* **39**, 2890 (1989).
37. Z.-X. Shen, P. A. P. Lindberg, D. S. Dessau, I. Lindau, W. E. Spicer, D. B. Mitzi, I. Bozvic and A. Kapitulnik, "Photoelectron energy loss study of the $Bi_2CaSr_2Cu_2O_8$ single crystal", *Phys. Rev. B* **39**, 4295 (1989).
38. Z.-X. Shen, P. A. P. Lindberg, P. Soukiassian, I. Lindau, W. E. Spicer, C. B. Eom, T. H. Geballe, "Nature of the states near EF of the $Bi_2CaSr_2Cu_2O_8$ and the $Bi_2Sr_2CuO_6$ Superconductors", *Phys. Rev. B* **39**, 823, (1989).
39. P. A. P. Lindberg, Z.-X. Shen, J. Hwang, C. K. Shih, I. Lindau, W. E. Spicer, D. B. Mitzi and A. Kapitulnik, "Electronic structure of the $La_{1+x}Ba_{2-x}Cu_3O_{7+\delta}$ system studied by photoelectron spectroscopy", *Solid State Communication* **69**, 27 (1989).
40. P. A. P. Lindberg, Z.-X. Shen, D.S. Dessau, B. O. Wells, A. Borg, W. Ellis, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "The electronic structure of $Bi_{2.0}Sr_{1.8}La_{0.3}Ca_{0.8}Cu_{2.1}O_{8+\delta}$ superconductors studied using ultraviolet and x-ray photoelectron spectroscopy", *Physica C* **159**, 649-653 (1989).
41. P. A. P. Lindberg, Z.-X. Shen, D.S. Dessau, B.O. Wells, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Energy dispersions of single crystalline $Bi_{2.0}Sr_{1.8}Ca_{0.8}La_{0.3}Cu_{2.1}O_{8+\delta}$ superconductors determined using angle-resolved photoelectron spectroscopy", *Phys. Rev. B* **40**, 5169 (1989).
42. P. A.P. Lindberg, Z.-X. Shen, B.O. Wells, D. S. Dessau, A. Borg, W. Ellis, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Spectroscopic evidence of two-dimensional character of the 90K $Bi_{2.0}Sr_{1.8}Ca_{0.8}La_{0.3}Cu_{2.1}O_{8+\delta}$ superconductor", *Applied Physics Letter s* **55**, 1141(1989).
43. P. A. P. Lindberg, Z.-X. Shen, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Photoemission study of the electronic structure of the $(Pr_{0.2}La_{0.8})(Ba_{1.875}La_{0.125})Cu_3O_{7-\delta}$ System", *Solid State Comm.*, **72**, 575-578 (1989).
44. P.A. P. Lindberg, Z.-X. Shen, B. O. Wells, D. S. Dessau, W.P. Ellis, A. Borg, J.-S. Kang, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik "Photoemission study of absorption mechanisms in $Bi_{2.0}Sr_{1.8}Ca_{0.8}La_{0.3}Cu_{2.1}O_{8+\delta}$ $BaBiO_3$ and

$Nd_{1.85}Ce_{0.15}CuO_4$", *Phys. Rev. B* **40**, 8840 (1989).

45. D.S. Dessau, Z.-X. Shen, P. A. P. Lindberg, B. O. Wells, W. P. Ellis, A. Borg, J.-S. Kang, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik "Electronic structure of $Pb_2Sr_2CaCu_3O_8$", *Phys. Rev B* **40**, 6726 (1989).
46. P.A.P. Lindberg, Z.-X. Shen, D.S. Dessau, B. O. Wells, A. Borg, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Electronic structure of single-crystalline $Bi_2(SrCaLa)_3Cu_2O_8$", *Physica C* **162-164**, 1313 (1989).
47. D. S. Dessau, Z.-X. Shen, P. A. P. Lindberg, B. O. Wells, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "The electronic structure of $Pb_2Sr_2CaCu_3O_8$ as studied by resonance photoemission", *Physica C* **162-164**, 1373 (1989).
48. P. A. P. Lindberg, Z.-X. Shen, B.O. Wells, D. B. Mitzi, I. Lindau, W.E. Spicer and A. Kapitulnik, "Electronic structure of clean and Ag-covered single crystalline $Bi_2Sr_2CuO_6$", *Phys. Rev. B* **40**, 8769 (1989).
49. P. A. P. Lindberg, B. O. Wells, Z.-X. Shen, D. S. Dessau, D. B. Mitzi, I. Lindau, W. E. Spicer and A. Kapitulnik, "Interaction of overlayers of Al and Rb with single crystalline surfaces of $Bi_2Sr_2CaCu_2O_8$", *J. of Appl. Phys.* **67**, 2667 (1990).
50. B. O. Wells, P.A. P. Lindberg, Z.-X. Shen, D. S. Dessau, I. Lindau, W. E. Spicer, D. B. Mitzi, A. Kapitulnik Nature of the valence band states in $Bi_2(SrCaLa)_3Cu_2O_8$ *Phys. Rev. B* **40**, 5259 (1989).
51. D. S. Dessau, R. S. List, Z.-X. Shen, A. J. Arko, R. Barttlet, B. O. Wells and W. E. Spicer, "Au overlayer on $YBa_2Cu_3O_7$ and $Bi_2Sr_2CaCu_2O_8$" *App. Phys. Lett.* **57**, 307 (1990).
52. Z.-X. Shen, J. W. Allen, P. A. P. Lindberg, D. S. Dessau, B. O. Wells, A. Borg, W. Ellis, J. S. Kang, S.-J. Oh, I. Lindau and W. E. Spicer, "Photoemission study of CoO, *Phys. Rev. B* **42** 1817-1828 (1990)-II.
53. Z. X. Shen, R. S. List, D. S. Dessau, F. Parmigiani, A. J. Arko, and R. Bartlett, B. O. Wells, I. Lindau, and W. E. Spicer, "Photoemission study of CuO and Cu_2O single crystals," *Phys. Rev. B* **42**, 8081-8085 (1990).
54. B. O. Wells, Z.-X. Shen, D. S. Dessau, W. E. Spicer, C. G. Olson, D. B. Mitzi, A. Kapitulnik, R. S. List, and A. Arko, "Angle-Resolved-Photoemission Study of $Bi_2Sr_2CaCu_2O_{8+d}$: Metallicity of the BiO Plane," *Phys. Rev. Lett.* **65**, 3056-3059 (1990).
55. P. A. P. Lindberg, Z.-X. Shen, W. E. Spicer, and I. Lindau, "Photoemission Studies of High-Temperature Superconductors," *Surf. Sci. Repts.* **11**, 1-138 (1990).

56. A. Behfar-Rad and S. Wong, "Fully monolithic self-aligned GaAs/AlGaAs single quantum well ridge laser," *Proceedings of Conference on Lasers and Electro-Optics*, p. 470, 1990.
57. A. Behfar-Rad, S. Wong and J. Ballantyne, "Travelling wave operation in a triangular-shaped monolithic semiconductor ring laser," *International Electron Devices Meeting Technical Digest*, p. 934, 1990.

58. T.-J. King, J. R. Pfiester, J. D. Shott, J. P. McVittie, and K. C. Saraswat,"A Polycrystalline-SiGe-Gate CMOS Technology," *Technical Digest,* IEEE International Electron Devices Meeting, December 1990, San Francisco, pp. 253-256.
59. T.-J. King, J. R. Pfiester, and K. C. Saraswat, "A Variable-Workfunction Polycrystalline-SiGe Gate Material for Submicron CMOS Technologies," submitted to *IEEE Electron Device Letters.*
60. T.-J. King, J. R. Pfiester, and K. C. Saraswat, "p-Channel Silicon-Germanium Thin-Film Transistors," submitted to *IEEE Electron Device Letters.*

61. G.P. Dudevoir, J.S. Chow, J.M. Cioffi and S. Kasturia, "Combined Equalization and Coding for T1 Data Rates on Carrier Service Area Digital Subscriber Loops", Int'l Conference on Comm. 89, Boston 6/89 (invited).
62. J.M. Cioffi and G.P. Dudevoir, "Data Transmission with Mean-Square Partial Response", Global Telcom Conference 89, Dallas 11/89
63. A. Ruiz, J.M. Cioffi and S. Kasturia, "Discrete Multiple Tone Modulation with Coset Coding for the Spectrally Shaped Channel", in review, *IEEE Transactions on Comm.*
64. J. T. Aslanis and J.M. Cioffi, "Capacity and Cutoff Rate of Digital Subscriber Loop with Near-End Crosstalk Noise", Int'l Conference on Comm. 89, Boston 6/89 (invited).
65. J. C. Tu, J. S. Chow, G. P. Dudevoir and J. M. Cioffi "Crosstalk-Limited Performance of a Computationally Efficient Multichannel Transceiver for High Rate Digital Subscriber Lines", Global Telcom Conference 89, Dallas 11/89 (invited), to appear 1990 Int'l Conf. on Comm.
66. S. Kasturia, J. M. Cioffi, "Precoding for Block Signaling and Shaped Signal Sets", Int'l Conference on Comm. 89, Boston 6/89
67. S. Kasturia and J. M. Cioffi, "Vector Coding with Decision Feedback Equalization for Partial Response Channels", Global Telecom Conference 88, Miami 11/88.
68. J. M. Cioffi and G. Dudevoir, "High-Speed Data Transmission on ISDN Loops", Int'l Conf. on Comm. Tech. 89, Beijing 7/89 (postponed).
69. S. Kasturia, J. T. Aslanis and J. M. Cioffi, "Vector Coding for Partial Response Channels", *IEEE Trasnactions on Information Theory,* 853, 1988.
70. J. S. Chow, J. C. Tu and J. M. Cioffi, "A Computationally Efficient Adaptive Transceiver for High-Speed Digital Subscriber Lines", to appear 1990 Int'l Conf. on Comm.

71. D. T. Slock and T. Kailath, "A Fast RLS Transversal Filter for Adaptive Linear Phase Filtering," *Inter'l. J. Adaptive Control and Signal Processing*, **2**, pp. 157-179, 1988.
72. A. Paulraj and T. Kailath, "Direction of arrival estimation by eigenstructure methods with imperfect spatial coherence of wavefronts", *J. Acoust. Soc. of America,* **83**(3):1034-1040, March 1988.
73. S. K. Rao and T. Kailath, "Regular iterative algorithms and their implementation on

processor arrays, *IEEE Proc.*, **76**(3):259-282, March 1988.

74. Y. Yoganadam, V. U. Reddy and T. Kailath, "Performance Analysis of the Adaptive Line Enhancer for Sinusoidal Signals in Broadband Noise," *IEEE Trans. ASSP*, **36**(11):1749-1757, November 1988.
75. Y. Bresler, V. U. Reddy, and T. Kailath, "Optimum Beamforming for Coherent Signal and Interferences," *IEEE Trans. ASSP*, **36**(6):833-843, June 1988.
76. D. T. Slock and T. Kailath, "Fast Transversal Filters with Data Sequence Weighting," *IEEE Trans. ASSP*, **37**(3):346-359, March 1989.
77. Y. Bistritz, H. Levi-Ari and T. Kailath, "Immittance-domain levinson algorithms, *IEEE Trans. Inform. Theory*, **35**(3):675-681, May 1989.
78. R. Roy and T. Kailath, "ESPRIT - Estimation of Signal Parameters via Rotational Invariance Techniques," *IEEE Trans. on ASSP*, **37**(7):984-995, July 1989.
79. B. Ottersten and T. Kailath, "Direction-of-arrival estimation for wideband signals using the ESPRIT algorithm, *IEEE Trans. Acoust. Speech Signal Process*, **38**(2):317-327, Feb. 1990.
80. K.-Y. Siu and J. Bruck, "Neural Computation of Arthmetic Functions", Special Issue on Neural Networks, *Proceedings of the IEEE*, 1669-1675, October 1990.
81. K.-Y. Siu and J. Bruck, "On the Power of Threshold circuity with Small Weights", to appear in *SIAM J. on Discrete Mathematics*.
82. K.-Y. Siu, J. Bruck and T. Kailath, "Depth Efficient Neural Networks for Division and Related Problems", submitted to the *IEEE Transactions on Information Theory*, Jan. 1991.
83. K.-Y. Siu, V. P. Roychowdhury and T. Kailath, "Computing with Almost Optimal Size Threshold Circuits", submitted to the *J. of Computer and System SciencesI*, July 1990.
84. V. P. Roychowdhury, K.-Y. Siu, A. Orlitsky and T. Kailath, "A Geometric Approach to Threshold Circuit Complexity," submitted to *IEEE Transactions on Computers*, Jan. 1991.
85. G. Xu and T. Kailath, "Direction-of-arrival estimation for wide-band sources via spectral smoothing", submitted to *IEEE Trans. on Signal Processing*, March 1990.
86. A. Dembo and T. Kailath, "Model-free distributed learning, *IEEE Trans. Neural Networks*, **1**(1):58-70, March 1990.
87. D. T. Slock, L. Chisci, H. Lev-Ari and T. Kailath, "Modular and numerically stable multichannel statistical signal processing, *IETE Technical Rev.*, **35**(2):51, Mar-Apr 1990.
88. D. Slock, L. Chisci, H. Lev-Ari and T. Kailath, "Modular and numerically stable multichannel FTF algorithms", *Proc. Intern'l. Conf. Acoustics, Speech and Signal Processing*, 1039-1041, Galsgow, Scotland, May 1989.
89. D. T. M. Slock and T. Kailath, "A modular multichannel multiexperiment fast transversal filter and a prewindowing framework for covariance RLS", submitted to *Signal Process.*
90. H. Lev-Ari, D. T. M. Slock, L. Chisci and T. Kailath, "Modular and numerically stable fast transversal filters for multichannel and multiexperiment RLS", submitted to *IEEE Trans. Acoust. Speech Signal Process.*